petroleum in each volume of rock. Even after drilling several exploration wells and also production wells in the development of an oil or gas field, the porosities and permeabilities are only known from the cores. Data from cores, cuttings and well logs must be extrapolated to produce a 3D model of the large volumes of rock between the wells. This must be based on predictions from facies distribution, distribution of faults and fault properties. Changes in reservoir properties as a function of depth require diagenetic models which can predict changes in porosity as a function of effective stress and temperature/time.

To calculate the producible oil in a prospect the total rock volume (Gross – G) in the structure must be estimated as well as the percentage of sand which can be produced (Net Sand – N).

The oil in place (V_p) is:

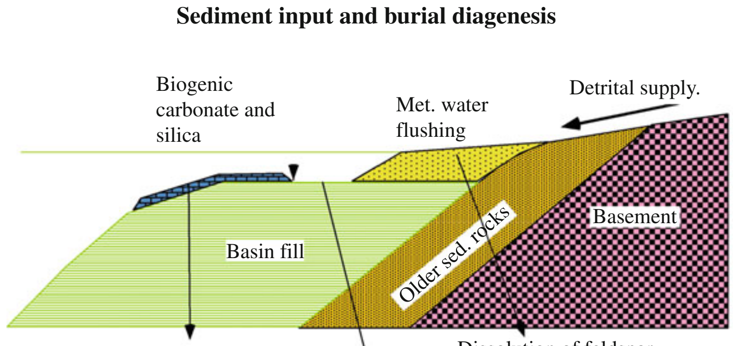
$$V_r \cdot \mathrm{N/G} \cdot \varphi\, O_{\mathrm{sat}}$$

Here V_r is the volume of rock between the oil/water contact (OWC) and the reservoir cap rock or the gas/oil contact. N/G (net/gross) is the ratio between the fraction of the reservoir rock that can be produced and the total volume of the reservoir rock. φ is the average porosity of the producible part of the reservoir (net volume). O_{sat} is the average saturation of oil; typically about 80–85% of the pores in sandstone are filled with oil. The remaining portion is water, which in siliciclastic rocks occupies the mineral surfaces and the smallest pores where the capillary entry pressure is too high for oil.

If the porosity is low the permeability will in most cases also be very low so that the flow of oil from the rock formation to the well becomes too slow to be economical. About 10% porosity may be the minimum porosity for defining the producible (net) part of the reservoir. In fractured reservoirs the permeability may be high even when the porosity is below 10%.

In the planning of production from an oil field, data from cores and logs from wells must be extrapolated into a 3D model of the flow properties of the reservoir.

The producible percentage of the oil in place is called the *recovery factor*, which may range from 20–30% up to 40–60%. In sandstones with good reservoir quality, improved production technology has in some cases (e.g. Statfjord and Gullfaks fields, offshore Norway) boosted the recovery factor to close on 70%. Recovery is limited both by the amount of oil remaining in the pores of the drained sandstones and the presence of undrained compartments within the reservoir where oil is bypassed. Reservoir quality is a very important factor in the financial risk assessment calculations for a prospect.



Burial depth 0-3.5(4) km	Carbonate cement Opal A-CT - quartz Little aut. kaolinite	Verdine(Fe) facies	Dissolution of feldspar and mica, precipitation of authigenic kaolinite $2KAlSi_3O_8 + 2H^+ + 9H_2O = Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+$
Burial depth > 3.5(4) km	Extensive quartz cementation Little illite if kaolinite and smectite are absent.	Chlorite coatings? Little quartz cement	Quartz cement, illitisation if kaolinite and K-feldspar is present $KAlSi_3O_8 + Al_2Si_2O_5(OH)_4 = KAl_3Si_3O_{10}(OH)_2 + 2SiO_2 + 2H_2O$

Fig. 4.17 Summary diagram for clastic diagenesis. The primary composition of the sand depends on the provenance, weathering, transport and depositional environment. Early diagenesis including meteoric flushing or marine cementation, is controlled by the depositional environment. Burial diagenesis is controlled by mineral stability (thermodynamics) and reaction rates (kinetics)

4.21 Conclusions

Diagenetic reactions are driven towards higher mechanical and chemical stability. Reactions in sandstones are driven by the effective stress from the overburden causing reduced porosity (volume) at temperatures below 70–80°C. At greater depth (higher temperatures) compaction is mostly chemical and mineral reactions are controlled by thermodynamics and kinetics. Because of low kinetic reaction rates (high activation energies) silicate reactions are very sensitive to temperature. The precipitation of quartz has high activation energy, and temperature is the main control on quartz cementation causing much of the porosity loss in well-sorted sandstones. The dissolution of K-feldspar and kaolinite at about 130°C occur because the mineral assemblage illite and quartz is more stable.

Because of the low solubility of silicate minerals and the limited flow of porewater in the deeper parts of sedimentary basins, burial diagenetic reactions must be nearly isochemical. Significant amounts of solids can not be exported from a sandstone and the porosity of a single reservoir rock will only decrease and can not increase during progressive burial.

Prediction of reservoir quality at great burial depth depends on the initial sediment composition (provenance), sedimentary facies (Fig. 4.17), early diagenetic processes and the subsequent burial history. This should therefore be linked to facies models and provenance in addition to basin subsidence and heat flow. Modelling of quartz cementation has proved to be very useful for the prediction of porosity as a function of the temperature history of the reservoir sandstones, but the results are sensitive to the primary textural and mineralogical composition of the sandstones and the presence of grain coatings.

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